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**US 6367320 B1** **US 6026640 A**

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(54) Abstract Title: **Correlating reductant injection with NOx leve**

(57) A method of mapping the rate of reductant injection required to reduce $NO_x$ catalytically in a lean-burn internal combustion engine exhaust gas, to meet a required standard, comprises measuring the $NO_x$ in the exhaust gas as the vehicle is driven and correlating the measured value with at least one measurable parameter indicative of a condition of the engine. The at least one measurable parameter may be at least one of exhaust gas temperature, mass flow of exhaust gas, manifold vacuum, ignition timing, engine speed, throttle position, the lambda value of the exhaust gas, quantity of fuel injected into the engine, amount of exhaust gas recirculation, and boost pressure. The correlated value may be used to determine the amount of reductant required to reduce the measured value of $NO_x$ to a desired level or by a desired amount.



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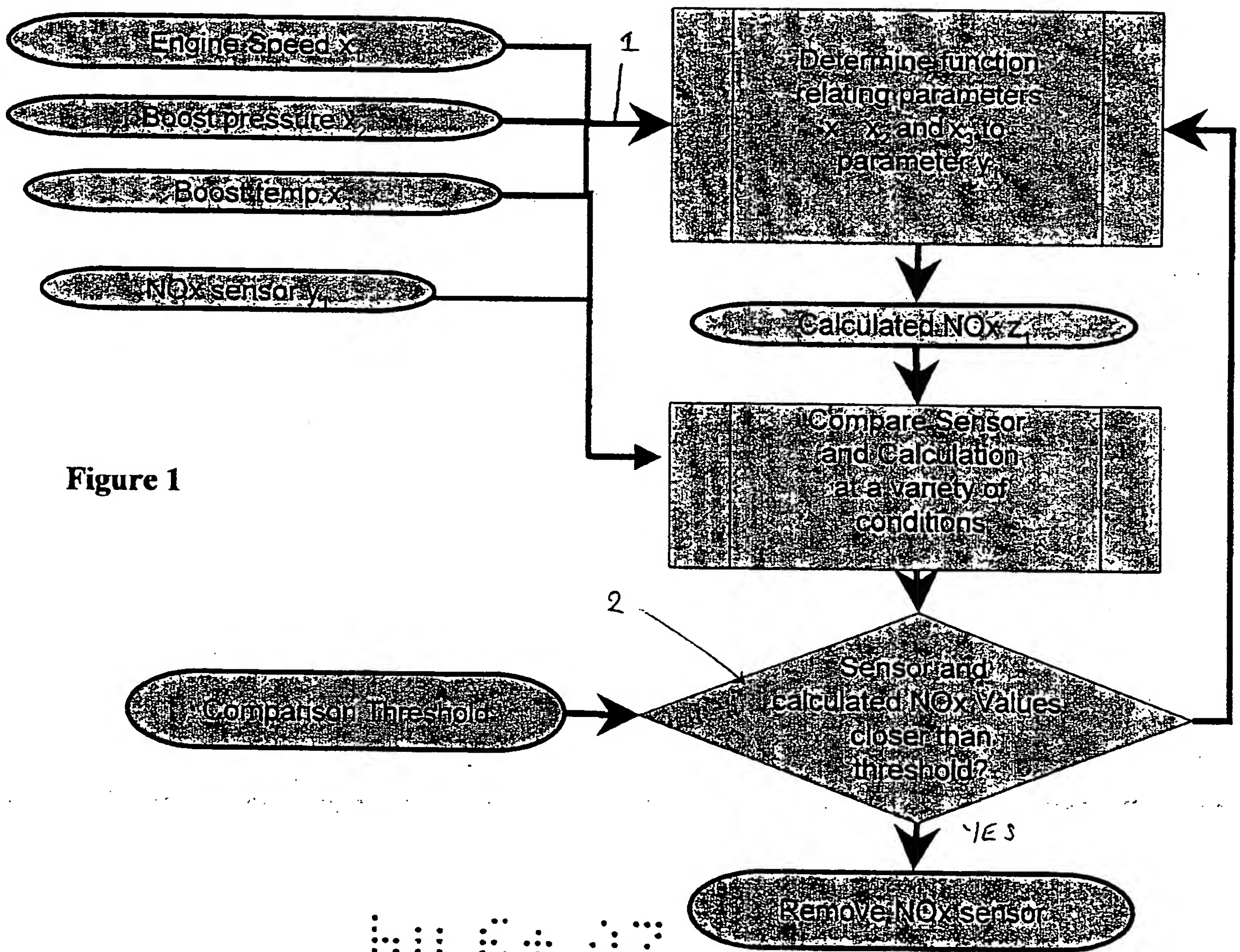

Engine Speed x
Boost pressure x
Boost temp x
NOx sensor y
Determine function relating parameters x, x2 and x to parameter y
Calculated NOx z
Compare Sensor and Calculation at a variety of conditions
Comparison Threshold
Sensor and calculated NOx Values closer than threshold?
No
YES
Remove NOx sensor


Figure 1

1/2

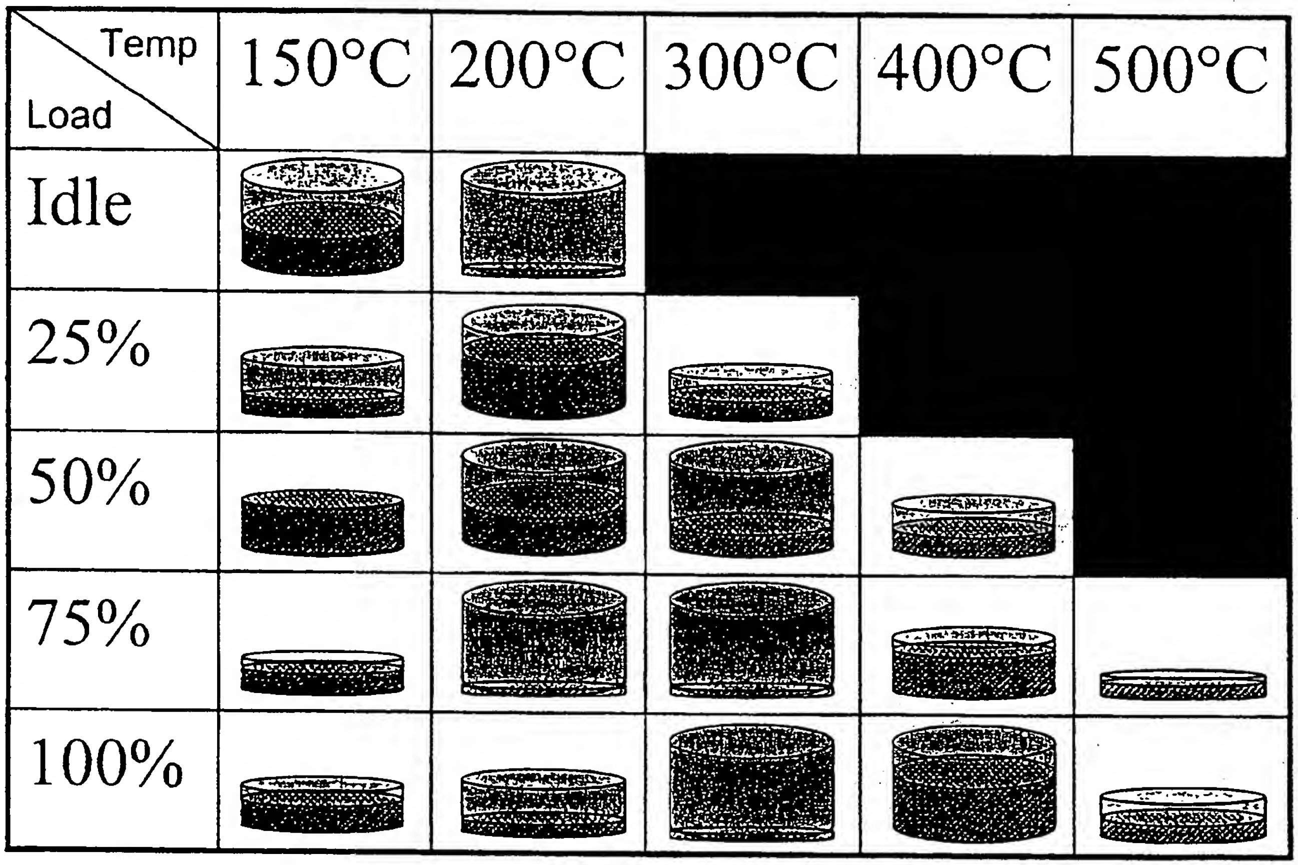


Fig. 2.

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# METHOD OF CALIBRATING REDUCTANT INJECTION

The present invention relates to a method and apparatus for mapping the rate of injection of a reductant required to reduce $NO_x$ catalytically over a drive cycle in vehicular lean-burn internal combustion engine exhaust gas for the purpose of *inter alia* reducing the $NO_x$ to $N_2$ to meet a desired emission standard.

By "$NO_x$" herein, we mean "nitrogen oxides" including nitrogen monoxide (NO) and nitrogen dioxide ($NO_2$). By "$NO_x$ sensors" herein, we mean sensors that measure total $NO_x$, sensors that can selectively detect the amount of NO in the $NO_x$ present, sensors that can selectively detect the amount of $NO_2$ in the $NO_x$ present and also $NO_x$ sensors which are cross-sensitive against ammonia for providing feedback control of reductant delivery in an exhaust system including a SCR catalyst. $NO_x$ sensors of the latter sort are described in "Development and evaluation of a $DeNO_x$ system based on urea SCR", by Martin Elsener *et al.*, MTZ worldwide, 11/2003, Volume 64, p. 28-31 (incorporated herein by reference) and are available from NGK, for example.

It is has been suggested to use neural networks (or fuzzy logic) in process design and process modelling in exhaust systems for internal combustion engines (see e.g. SAE 2000-01-0212 "Three-way Catalytic Converter Modelling: Neural Networks and Genetic Algorithm for the Reaction Kinetics Submodel", L. Glielmo *et al.*, incorporated herein by reference). In computing terms, neural networks have a number of advantages over theoretical modelling or modelling based on experimentally measured input-output data to build an empirical model. They can learn from experience; generalise from examples; and abstract essential information from "noisy" data. However, they can only provide good results for certain types of problem, and then only when a great deal of care is taken over neural network design and input data pre-processing data.

Reductant injection into exhaust systems of lean-burn internal combustion engines for the purpose of reducing $NO_x$ to $N_2$ over a suitable catalyst is known. Where the reductant is a hydrocarbon, such as the fuel used to power the engine, the technology is generally called lean $NO_x$ catalysis and the catalysts are called lean $NO_x$ catalysts, denox catalysts, lean $NO_x$ reduction catalysts or $NO_x$ occluding catalysts. Typical lean

$NO_x$ catalysts are copper exchanged zeolite e.g. ZSM5 or platinum on alumina. $NO_x$ in the exhaust gas competes with other oxidising agents such as oxygen ($O_2$) for the hydrocarbon, and $NO_x$ conversion in a drive cycle is of the order of about 40%.

Where the reductant is a $NO_x$ specific reactant, the technique is generally termed "selective catalytic reduction" or SCR and reduction is more selective than lean $NO_x$ catalysis. Typical catalysts comprise platinum, vanadium ($V_2O_5$) supported e.g. on titania ($TiO_2$) or zeolites such as mordenite.

By "$NO_x$ specific reactant" herein, we mean a reducing agent that, in most conditions, preferentially reduces $NO_x$ over other components of a gaseous mixture. Examples of $NO_x$-specific reactants include nitrogenous compounds such as nitrogen hydrides, e.g. ammonia ($NH_3$) or hydrazine, or an $NH_3$ precursor.

By "$NH_3$ precursor" we mean one or more compounds from which $NH_3$ can be derived, e.g. by hydrolysis. These include urea ($CO(NH_2)_2$) as an aqueous solution or as a solid or ammonium carbamate ($NH_2COONH_4$). If the urea is used as an aqueous solution, a eutectic mixture, e.g. a 32.5% $NH_3$ (aq), is preferred. Additives can be included in the aqueous solutions to reduce the crystallisation temperature.

Urea hydrolyses at temperatures above 160°C according to equation (1) to liberate $NH_3$ itself. It is also believed to decompose thermally at this temperature and above according to equations (2) and (3) resulting in reduction of $NO_x$, as evidenced by formation of CO during SCR processes with urea (see SAE 900496 and SAE 930363 (both incorporated herein by reference)).

$$CO(NH_2)_2 + H_2O \rightarrow 2NH_3 + CO_2 \qquad (1)$$

$$CO(NH_2)_2 \rightarrow .NH_2 + CO \qquad (2)$$

$$.NH_2 + NO \rightarrow N_2 + H_2O \qquad (3)$$

The $NH_3$ can be in anhydrous form or in the form of an aqueous solution, for example.

The application of $NH_3$ SCR technology to treat $NO_x$ emissions from IC engines, particularly lean-burn IC engines, is well known. Several chemical reactions occur in the $NH_3$ SCR system, all of which represent desirable reactions which reduce $NO_x$ to elemental nitrogen. The overall desired reaction is represented in equation (4).

$$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O \tag{4}$$

Competing, non-selective reactions with oxygen can produce secondary emissions or may unproductively consume $NH_3$. One such non-selective reaction is the complete oxidation of $NH_3$, represented in equation (5).

$$4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O \tag{5}$$

Presently, urea is the preferred source of $NH_3$ for mobile applications because it is less toxic than $NH_3$, it is easy to transport and handle, is inexpensive and commonly available.

Early methods of using urea as a source of $NH_3$ in exhaust systems involved injecting urea directly into the exhaust gas, optionally over an in-line hydrolysis catalyst (see EP-A-0487886 (incorporated herein by reference)). However, not all urea is hydrolysed in such arrangements, particularly at lower temperatures.

Incomplete hydrolysis of urea can lead to increased PM emissions on tests for meeting the relevant emission test cycle because partially hydrolysed urea solids or droplets will be trapped by the filter paper used in the legislative test for PM and counted as PM mass. Furthermore, the release of certain products of incomplete urea hydrolysis, such as cyanuric acid, is environmentally undesirable. Another method is to use a pre-injection hydrolysis reactor (see US-A-5,968,464 (incorporated herein by reference)) held at a temperature above that at which urea hydrolyses.

It will be appreciated that at lower temperatures, below about 100-200°C, $NH_3$ can also react with $NO_2$ to produce an explosive mixture of ammonium nitrate and ammonium nitrite according to equation (6):

$$2NH_3 + 2NO_2 + H_2O \rightarrow NH_4NO_3 + NH_4NO_2 \quad (6)$$

For the avoidance of doubt, in so far as the invention uses $NH_3$-SCR, the present invention does not embrace such reactions or the promotion of conditions which bring them about. For example, the reaction can be avoided by ensuring that the temperature does not fall below about 200°C or by supplying into a gas stream less than the precise amount of $NH_3$ necessary for the stoichiometric reaction with $NO_x$ (1 to 1 mole ratio). For cold start applications, measures to prevent water from contacting the catalyst can be adopted. These can include locating a water trap, e.g. a zeolite, upstream of the catalyst to reduce the amount of water vapour contacting the catalyst until it is heated sufficiently. A water trap can also be positioned downstream of the catalyst, to prevent atmospheric humid air from travelling up the exhaust pipe. An electric heater can also be employed to drive off moisture from the catalyst pre-cold start. Such arrangements are described in our EP 0747581, (incorporated herein by reference).

One problem in adopting SCR or lean $NO_x$ technology is in controlling the addition of the reductant: if too little reductant is added, $NO_x$ conversion may be insufficient to meet a relevant emission standard. On the other hand, if there is too much reductant it may be exhausted to atmosphere - hydrocarbon is a legislated pollutant and $NH_3$ is a biological poison and is detected as $NO_x$ in tests for meeting such standards.

In order to avoid such problems, extensive bench testing and modelling is carried out to establish engine maps and look-up tables to match e.g. urea injection to engine-out $NO_x$. However, such testing is time consuming and extremely expensive.

We have now devised a method of establishing such maps and look-up tables which overcomes problems associated with the prior art and is particularly applicable to the retrofit market. In retrofit applications, the invention is based on the idea of fitting at least one $NO_x$ sensor to the exhaust system of the vehicle, preferably downstream of the SCR or lean $NO_x$ catalyst, to input measurements on $NO_x$ detected in the system to suitable processor means, e.g. the vehicle's electronic control unit (ECU). The ECU may be the engine control unit or separate therefrom but in communication with the engine control unit. In one embodiment, the ECU is used to correlate the detected $NO_x$ values

with at least one detectable parameter indicative of the condition of the engine. The vehicle is then driven normally for a period sufficient to collect enough correlated data to enable the amount of $NO_x$ in the exhaust gas to be predicted to a desired level of accuracy by looking up a detected value of the at least one parameter. The at least one $NO_x$ sensor can then be removed, if desired, and the rate of reductant injection can be controlled in response to the detected input of the at least one parameter, so that the exhaust system meets the relevant emission standard.

Accordingly, the expense and time normally required to develop maps for reductant injection can be avoided. Furthermore, since certain embodiments of the invention comprise empirical determination of the amount of reductant required to treat $NO_x$ in the exhaust gas, the method is more likely to reduce $NO_x$ emissions than data generated from models or bench testing. A further advantage resides in the fact that, since $NO_x$ sensors can be removed following mapping, the problems of $NO_x$ sensor cost and durability can be reduced or avoided. Moreover, it is known from e.g. EP 1054722 that $NO_x$ conversion over certain SCR catalysts can be improved if the $NO:NO_2$ ratio is adjusted to a particular range of values. Accordingly, by positioning at least one $NO_x$ sensor upstream of the SCR or lean $NO_x$ catalyst, it may also be possible to adjust $NO:NO_2$ ratio e.g. at selected temperatures for optimal $NO_x$ conversion.

The methods of the invention can use established techniques such as neural network technology. Adequate safeguards such as "mop-up" oxidation catalysts to prevent excessive emission of hydrocarbon or $NH_3$ to atmosphere during collection of such generalisation data or testing of training algorithm can be provided as necessary.

Therefore, according to a first aspect, the invention provides a method of mapping the rate of reductant injection required to reduce $NO_x$ catalytically over a drive cycle in vehicular lean-burn internal combustion engine exhaust gas flowing in an exhaust system, thereby to meet a desired emission standard, which method comprising the steps of (i) measuring $NO_x$ in the exhaust gas as the vehicle is driven and (ii) correlating the measured $NO_x$ value with a value of at least one measurable parameter indicative of a condition of the engine.

In one embodiment, the method comprises the step (iii) of determining what rate of reductant injection is required catalytically to reduce the measured value of $NO_x$ to/by a desired amount for the correlated parameter value.

In its broadest aspect, the collected correlated data is analysed "off-vehicle", either by removing the means for collecting the data, or downloading the data from the means for collecting the data. Such analysis can include a determination of what rate of reductant injection is required catalytically to reduce a measured value of $NO_X$ to/by a desired amount for the correlated parameter value. However, in a preferred embodiment, such determination of what rate of reductant injection is required is also performed as the vehicle is driven by suitable processor means and appropriate feedback e.g. by measuring $NO_X$ and/or reductant e.g. downstream of the catalyst to provide empiric "finessing" of the rate of reductant injection to arrive at a recalculated rate of reductant injection, as necessary. Such a "learned" response is an aspect of neural network or "fuzzy logic" technology.

Therefore, according to a further embodiment, the method comprises the step of (iv) injecting reductant at the rate determined in step (iii) when the correlated parameter value is detected as the vehicle is driven, analysing exhaust gas downstream of the catalytic reduction step for the presence of reductant and/or $NO_x$ and recalculating the rate determined according to step (iii) in order to reduce $NO_x$ emissions and/or prevent reductant slip as necessary.

In an embodiment the or each correlation step, the or each step of determining or recalculating what rate of reductant injection is required is performed by a processor. Such processor can be part of an electronic control unit (ECU).

According to a further embodiment, the correlated values, the rates of reductant injection determined and/or the recalculated rates of reductant injection are stored as look-up tables or maps, for example, in the ECU.

Ordinarily, modern vehicle ECU's for controlling engine function do not have the processor and/or storage capability necessary for applying the methods according to the

first and second aspects of the invention. It is envisaged, therefore, that the vehicle ECU can be removed and replaced for the period of mapping with an ECU with the necessary processor and/or storage capacity. Following the mapping procedure, the original ECU can be re-programmed with the appropriate look up tables or maps and algorithms or a fresh ECU so-programmed can be inserted. Of course, if the original ECU of the vehicle has the required processor and/or storage capacity, no such ECU switching/re-programming is necessary. Alternatively, the capacity of the original ECU can be supplemented by additional processor/storage capacity for the period of the analysis.

A further advantage of the present invention is that a plurality of vehicles sharing similar drive cycles can be fitted with appropriately programmed ECUs, whereas the data need be collected from only one such vehicle.

The method of the present invention is particularly applicable to the retrofit market, e.g. so that vehicles can meet certified standards to enter areas, such as parts of cities, wherein access is denied to vehicles not meeting proscribed emissions standards. Therefore, according to a second aspect, the invention provides a method of retrofitting a vehicle comprising a lean-burn internal combustion engine with a system for meeting a desired emission standard for $NO_x$, which system comprising means for injecting a reductant into exhaust gas and a catalyst for reducing $NO_x$ to $N_2$ with the reductant, which method comprising fitting the existing exhaust system with at least one $NO_x$ sensor for measuring $NO_x$ in the exhaust gas as the vehicle is driven and means for correlating a measured $NO_x$ value with a value of at least one measurable parameter indicative of a condition of the engine

In one particular embodiment according to the second aspect of the invention, $NO_x$ is detected using at least one $NO_x$ sensor fitted either upstream and/or downstream of the catalyst. However, since $NO_x$ sensors are expensive and have limited durability, the invention comprises the steps of removing the at least one $NO_x$ sensor from the exhaust system when sufficient data points have been collected for the correlation of measured $NO_x$ with the at least one measurable parameter to determine what rate of reductant injection is required to reduce $NO_x$ on the catalyst over a drive cycle to meet a relevant emission standard.

The at least one measurable parameter can be any parameter indicative of a condition of the engine. It is envisaged that one or more of the following may be used: exhaust gas temperature; mass flow of exhaust gas in the system; manifold vacuum; ignition timing; engine speed; throttle position (accelerator position); the lambda value of the exhaust gas; the quantity of fuel injected in the engine; the position of the exhaust gas recirculation (EGR) valve and thereby the amount of EGR; boost pressure; and engine coolant temperature. Sensors for measuring all these parameters are known to the skilled person.

The reductant can be a hydrocarbon and the catalyst can be a lean $NO_x$ catalyst e.g. any of those mentioned above, or the reductant can be a $NO_x$ specific reactant, such as a nitrogen hydride, e.g. ammonia ($NH_3$) or hydrazine, or an $NH_3$ precursor and the catalyst can be a SCR catalyst such as a platinum-based catalyst, a supported vanadium such as $V_2O_5/TiO_2$ or a zeolite, such as mordenite. The $NH_3$ precursor can be urea ($CO(NH_2)_2$) or ammonium carbamate ($NH_2COONH_4$), for example.

According to a third aspect, the invention comprises an apparatus for mapping the rate of reductant injection required to reduce $NO_x$ catalytically in exhaust gas of a vehicle comprising a lean-burn internal combustion engine and an exhaust system comprising a catalyst for reducing $NO_x$ to $N_2$ with the reductant, thereby to meet a desired emission standard for $NO_x$, which apparatus comprising at least one $NO_x$ sensor for measuring $NO_x$ in the exhaust gas, means for measuring at least one measurable parameter indicative of a condition of the engine and means for correlating the measured $NO_x$ value with the value for the at least one measurable parameter.

In one embodiment, the at least one $NO_x$ sensor is located downstream of the catalyst. Where the system also includes a reductant sensor, this can also be positioned downstream of the catalyst. The system can also comprise a source of reductant, e.g. a hydrocarbon fuel such as diesel or a $NO_x$ specific reactant as defined herein.

According to a fourth aspect, the invention provides a vehicle comprising an apparatus according to the invention. Such vehicle can be powered by any suitable fuel

such as gasoline or preferably diesel. Alternative fuel such as liquid petroleum gas, natural gas and methanol may also be used.

Where the vehicle comprises a diesel engine, it can be a heavy-duty diesel engine or light duty diesel engine according to the relevant legislation.

In order that the invention may be more fully understood, reference will be made to the accompanying drawings, in which:

Figure 1 is a flowchart illustrating the method steps involved in replacing a $NO_x$ sensor with a $NO_x$ calculation algorithm, according to the invention; and

Figure 2 is a flowchart illustrating the bin concept of threshold comparisons.

Referring to Figure 1, at step 1, the function creation algorithm reads-in parameters $x_1$, $x_2$, $x_3$ and $y_1$ The function determines a relationship between $x_1$, $x_2$ and $x_3$ that would allow $y_1$ to be calculated without the sensor $y_1$ being connected to Engine Control Unit (ECU).

At step 2, the signal from the function determining a relationship between $x_1$, $x_2$ and $x_3$ that calculates $z_1$ is compared to the signal from the sensor $y_1$. If the $NO_x$ sensor signal $y_1$ and the calculated $NO_x$ signal $z_1$ are not close enough to meet the threshold comparisons then the function determining the relationship between $x_1$, $x_2$ and $x_3$ and $y_1$ continues to be adapted until the difference between calculated signal $z_1$ and the real sensor signal $y_1$ is within the pre-determined comparison threshold at a variety of conditions. However, if the difference between calculated signal $z_1$ and the real sensor signal $y_1$ is within the pre-determined comparison threshold at a variety of conditions and for a sufficient time, the ECU is configured to alert the operator that the sensor can be removed.

Referring now to Figure 2, it can be seen that most of the temperature/load windows in the table have bins in them; some of the windows do not have bins in them because the conditions are not reached by the vehicle. The height of the bin is related to

the length of time the vehicle has spent at each of the windows. The tallest bins represent a few hours, the smallest just a few minutes. Each of the bins has a "fill" level; the level of fill indicates how much time the sensor signals $y_1$ and $z_1$ (see Figure 1) have been within the comparison threshold (see Figure 1). The example illustrated in Figure 2 shows an early level of the function calculating $z_1$. It can be seen that in the 50% load, 150°C window, the signals $z_1$ and $y_1$ are within the threshold 100% of the time, whereas in the 75% load 300°C window, it can be seen that there is less than 5% correlation between $z_1$ and $y_1$.

**CLAIMS:**

1. A method of mapping the rate of reductant injection required to reduce $NO_x$ catalytically over a drive cycle in vehicular lean-burn internal combustion engine exhaust gas flowing in an exhaust system, thereby to meet a desired emission standard, which method comprising the steps of (i) measuring $NO_x$ in the exhaust gas as the vehicle is driven and (ii) correlating the measured $NO_x$ value with a value of at least one measurable parameter indicative of a condition of the engine.

2. A method according to claim 1, comprising the step (iii) determining what rate of reductant injection is required catalytically to reduce the measured value of $NO_x$ to/by a desired amount for the correlated parameter value.

3. A method according to claim 2, comprising the step of (iv) injecting reductant at the rate determined in step (iii) when the correlated parameter value is detected as the vehicle is driven, analysing exhaust gas downstream of the catalytic reduction step for the presence of reductant and/or $NO_x$ and recalculating the rate determined according to step (iii) in order to reduce $NO_x$ emissions and/or prevent reductant slip as necessary.

4. A method according to claim 1, 2 or 3, wherein the or each correlation step and/or the or each step of determining or recalculating what rate of reductant injection is required is performed by a processor.

5. A method according to claim 4, wherein the processor is part of an electronic control unit (ECU).

6. A method according to any of claims 1 to 5, wherein the correlated values, the rates of reductant injection determined and/or the recalculated rates of reductant injection are stored as look-up tables or maps.

7. A method according to claim 6, wherein the correlated values and/or rates are stored on an ECU.

8. A method according to claim 5 or 7, wherein the ECU used to perform the or each correlation step, to determine the or each rate of reductant injection and/or to determine the or each recalculated rate of reductant injection is replaced with an ECU programmed with look-up tables or maps comprising the determined or recalculated rate of reductant injection required for any detected value of the at least one measurable parameter.

9. A method according to any preceding claim, wherein the at least one measurable parameter is at least one of exhaust gas temperature; mass flow of exhaust gas in the system; manifold vacuum; ignition timing; engine speed; throttle position; the lambda value of the exhaust gas; the quantity of fuel injected in the engine; the position of the exhaust gas recirculation (EGR) valve and thereby the amount of EGR; and boost pressure.

10. A method according to any preceding claim, wherein the reductant is a $NO_x$ specific reactant, such as a nitrogen hydride, e.g. ammonia ($NH_3$) or hydrazine, or an $NH_3$ precursor.

11. A method according to claim 10, wherein the $NH_3$ precursor is urea ($CO(NH_2)_2$) or ammonium carbamate ($NH_2COONH_4$).

12. A method of retrofitting a vehicle comprising a lean-burn internal combustion engine with a system for meeting a desired emission standard for $NO_x$, which system comprising means for injecting a reductant into exhaust gas and a catalyst for reducing $NO_x$ to $N_2$ with the reductant, which method comprising fitting the existing exhaust system with at least one $NO_x$ sensor for measuring $NO_x$ in the exhaust gas as the vehicle is driven and means for correlating a measured $NO_x$ value with a value of at least one measurable parameter indicative of a condition of the engine.

13. A method according to claim 12, wherein the at least one $NO_x$ sensor is removed from the exhaust system when sufficient data points have been collected for the correlation of measured $NO_x$ with the at least one measurable parameter to determine

what rate of reductant injection is required to reduce $NO_x$ on the catalyst over a drive cycle to meet a relevant emission standard.

14. Apparatus for mapping the rate of reductant injection required catalytically to reduce $NO_x$ in exhaust gas of a vehicle comprising a lean-burn internal combustion engine and an exhaust system comprising a catalyst for reducing $NO_x$ by a desired amount with the reductant, thereby to meet a desired emission standard for $NO_x$, which apparatus comprising at least one $NO_x$ sensor for measuring $NO_x$ in the exhaust gas, means for measuring at least one measurable parameter indicative of a condition of the engine and means for correlating the measured $NO_x$ value with the value for the at least one measurable parameter.

15. Apparatus according to claim 14, comprising reductant injection means and means for controlling the injection means to inject reductant into the exhaust gas at a desired rate.

16. Apparatus according to claim 15, comprising means for using the correlated parameter value to determine the rate of reductant injection required catalytically to reduce the $NO_x$ to $N_2$.

17. Apparatus according to claim 16, comprising means for measuring exhaust gas downstream of the catalyst for the presence of reductant and $NO_x$ and recalculating the rate of reductant injection for that measured parameter value to reduce $NO_x$ emissions and/or prevent reductant slip, as necessary.

18. Apparatus according to claim 14, 15, 16 or 17, wherein the correlating means, the reductant rate injection determining means, the injection controlling means and/or the reductant rate recalculating means comprises a processor.

19. Apparatus according to claim 14 to 18, comprising means for storing the correlated values, the rates of reductant injection determined and/or the recalculated rates of reductant injection as look-up tables or maps.

20. Apparatus according to claim 18 or 19, wherein the processor and/or the storing means is part of the electronic control unit (ECU).

21. Apparatus according to any of claims 14 to 20, wherein the at least one $NO_x$ sensor is positioned upstream and/or downstream of the catalyst.

22. Apparatus according to any of claims 14 to 21, comprising means for detecting reductant in exhaust gas downstream of the catalyst.

23. Apparatus according to any of claims 14 to 22, wherein the catalyst comprises copper exchanged zeolite, such as Cu/ZSM5, or platinum e.g. platinum on alumina.

24. Apparatus according to any of claims 14 to 22, wherein the catalyst comprises supported vanadium such as $V_2O_5/TiO_2$ or a zeolite, such as mordenite.

25. Apparatus according to any of claims 14 to 24, further comprising a source of reductant.

26. Apparatus according to any of claims 14 to 25, wherein the means for measuring at least one measurable parameter indicative of a condition of the engine measures at least one of exhaust gas temperature; mass flow of exhaust gas in the system; manifold vacuum; ignition timing; engine speed; throttle position; the lambda value of the exhaust gas; the quantity of fuel injected in the engine; the position of the exhaust gas recirculation (EGR) valve and thereby the amount of EGR; and boost pressure.

27. A vehicle comprising an apparatus according to any of claims 14 to 26.

28. A vehicle according to claim 27, wherein the engine is a diesel engine, such as a heavy-duty diesel engine.

29. A method of mapping the rate of reductant injection required catalytically to reduce $NO_x$ over a drive cycle in vehicular lean-burn internal combustion engine exhaust gas thereby to meet a desired emission standard substantially as described herein.

30. A method of retrofitting a vehicle comprising a lean-burn internal combustion engine with a system for meeting a desired emission standard for $NO_x$, which system comprising means for injecting a reductant into exhaust gas and a catalyst for reducing $NO_x$ to $N_2$ with the reductant substantially as described herein.

31. Apparatus for mapping the rate of reductant injection required catalytically to reduce $NO_x$ in exhaust gas of a vehicle comprising a lean-burn internal combustion engine and an exhaust system comprising a catalyst for reducing $NO_x$ to $N_2$ with the reductant, thereby to meet a desired emission standard for $NO_x$ substantially as described herein.

32. A vehicle comprising an apparatus according to the invention substantially as described herein.

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16

INVESTOR IN PEOPLE

**Application No:** GB0414061.2 **Examiner:** Dave Woolf

**Claims searched:** 1-32 **Date of search:** 27 July 2004

## Patents Act 1977: Search Report under Section 17

**Documents considered to be relevant:**

| Category | Relevant to claims | Identity of document and passage or figure of particular reference |
|---|---|---|
| A | - | US 6367320 B1 (KUEPER) Column 2 lines 17-56 and column 3 lines 26-54. |
| A | - | US 6026640 A (KATO) Whole document. |

Categories:

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|---|---|---|---|
| X | Document indicating lack of novelty or inventive step | A | Document indicating technological background and/or state of the art |
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**Field of Search:**

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Worldwide search of patent documents classified in the following areas of the IPC$^{07}$

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The following online and other databases have been used in the preparation of this search report

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